Anatomical Studies of the Collateral Blood Supply to the Brain and Upper Extremity

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The last decade has brought a growing interest in cerebrovascular insufficiency associated with occlusion of the vertebral arteries and vessels contributing blood to these arteries.12,13,22,27,42 As one aspect of the problem, we have been studying the collateral circulation to determine the details of its channels of circulation and their interrelationship.

Review of Past Studies

Consideration has been given in the literature to such factors as lesions in the cervical vertebrae, head movements, and anatomical variants; the incidence and character of angiographical changes have also been carefully analyzed.1,2,6,13,15,17,22,24,27,33,34,46,55,56,60 Detailed descriptions have been given of the clinical forms of these circulatory disturbances.27,31,38 Attention has been called to the "subclavian steal syndrome."18,19,21,25,26,37,39,42,47,58 Further clinical studies have been stimulated by the development of surgery of the blood vessels leaving the aortic arch.10,11,16,19,21,25,27,64 De Bakey, et al.,12,13 reported endarterectomies performed on the common and internal carotid, vertebral, and subclavian arteries, and brachiocephalic trunk.

The inconsistencies noted between the clinical picture, angiographic changes, and the autopsy findings are interesting. It is obvious that the various clinical pictures encountered may be conditioned by a related variety in the sites of the occlusive lesions. This, however, does not explain the variety of clinical syndromes that occur with the identical sites of occlusion. The role of compensatory factors should not be underestimated, and attention to the problem of collateral circulation seems justified.

In postmortem investigations, Schultze and Sauerbrey44 showed that the anastomoses between the occipital artery and vertebral arteries are constant. The presence of these connections has also been proved in angiographical examinations.27,40,41,45,59

Cooper9 demonstrated the connection between the superior and inferior thyroid arteries; he also demonstrated the presence of contrast medium in the vertebral artery distal to the site of the carotid or vertebral ligation. Ljubomudrow30 showed that possible channels of collateral circulation are the arterial branches (and their connections) of the inferior and superior thyroid, ascending and transversing cervical, superior intercostal, and posterior auricular arteries.

In 1956, Whisnant and coworkers57 performed similar investigations on 12 dogs, ligating the carotid and vertebral arteries. As a rule the dogs survived the operations, and some showed little sign of damage to the central nervous system. In nine other dogs, the authors tried to limit the flow of blood to the brain by ligating both vertebral arteries at the level of the transverse process of the sixth vertebra, both the common external and internal arteries, and also the pharyngeal ascending artery and the occipital arteries. Coma was observed in only three dogs, while in others the symptoms were hardly noticeable. Postmortem examinations showed no important damage in the cerebral tissue in seven of the nine animals. Injection of contrast medium into the arterial system demonstrated the role of the internal thoracic artery and of the costo-cervical trunk as possible channels of collateral blood supply.

New data concerning the channels of collateral circulation were revealed by angiographic examinations performed in patients with occlusive lesions of vessels leaving the aortic arch and with traumatic lesions of arteries supplying the upper extremity.5,5,18,20,29,32,34,35,38,39,47 These examinations emphasized the following anastomo-
si connections: between the ascending cervi-
cical and deep cervical arteries, and the vertebral artery; between the external caro-
tid and ascending cervical arteries; between the two vertebral arteries; between the two in-
ferior thyroid arteries; between the superior and inferior thyroid arteries; and between the
two internal thoracic arteries.

In earlier studies we identified an area Sza-
piero calls the “anterior aorto-cerebral cir-
cle.” This area is especially impor-
tant to the collateral circulation of the brain and retina. We are reporting here experi-
ments concerned with the connections be-
tween the “anterior aorto-cerebral circle” and other vascular areas. The term “posterior aorto-cerebral circle” covers the arterial terrain bounded by the aortic arch, the right brachiocephalic trunk, the proximal portion of the subclavian arteries (Fig. 1), and the vertebral arteries joining to form the basilar artery.

Material and Methods

Our postmortem studies were made on patients who died of various diseases. As in the previous experiments, occlusive ligatures were placed on certain arteries and their connections to demonstrate the collateral blood circulation after injection of preserved blood or artificial materials such as synthetic latex plus Micropaque to obtain radiological verification. A total of 40 such experiments were carried out, which we divided into three main groups illustrated by Figs. 1–3.

Numbers in Fig. 1 and subsequent figures indicate the following arteries:

1. Vertebral artery
2. External carotid artery
3. Occipital artery
4. Subclavian artery
5. Thyro-cervical trunk
6. Transverse cervical artery
7. Costo-cervical trunk
8. Clamp of the brachio-cephalic trunk
9. Anterior and posterior intercostal arteries
10. Anastomoses between anterior and posterior intercostal arteries and the branches of the axillary artery
11. Axillary artery
12. Brachial artery
13. Internal thoracic artery
14. Superior thoracic artery
15. Acromio-thoracic artery
16. Lateral thoracic artery
17. Aorta
18. Ophthalmic artery.

Results

Collateral Circulation Between the Verteb-
ral Artery and the External Carotid Artery. One group of experiments concerned circu-
lion between the vertebral and external caro-
tid arteries. As shown in Fig. 1 B, latex medium or preserved blood injected into the vertebral artery reached the external carotid artery and its branches, although the verte-
bral artery had previously been ligated intra-
cranially. The medium also reached the sub-
clavian artery through anastomoses between
the vertebral artery and the branches of the
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Fig. 1 B. Preserved blood injected into the vertebral artery (black arrow) reached the external carotid artery (2). The vertebral (1) had previously been ligated intracranially.

Fig. 1 D. Opaque medium injected into the external carotid artery (black arrow) filled both vertebral arteries (1) and the basilar artery. The anastomoses between the occipital artery (3) and vertebral arteries are seen.

subclavian artery. Opaque medium injected into the occipital artery filled the vertebral artery through branches between them (Fig. 1 C). Contrast medium injected into the external carotid artery filled both vertebral arteries and the basilar artery (Fig. 1 D). The anastomoses between the occipital artery and the vertebral arteries were clearly seen.

Collateral Circulation Between the Vertebral Artery and Branches of the Subclavian Artery. A second group of experiments (Fig. 2 A) showed that latex medium or preserved blood injected into the intracranial portion of the vertebral artery filled the thyro-cervical trunk, the transverse artery, and the costo-cervical trunk, despite the fact that the vertebral artery had previously been ligated at its origin.

Experiments also showed that medium or preserved blood injected into the ascending cervical artery (which is a branch of thyrocervical trunk) filled the vertebral artery through the anastomoses between them (Fig. 2 B). The medium when injected into the transverse cervical artery reached the vertebral artery through the anastomoses between

Fig. 1 C. Opaque medium injected into the occipital artery (white arrow) reached the vertebral artery (1).
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FIG. 2 A. Contrast medium injected into the vertebral artery (black arrow) in its intracranial course filled the thyro-cervical trunk (5), the transverse cervical artery (6), and the costo-cervical trunk (7). The vertebral artery had previously been ligated at its origin.

them (Fig. 2 C). The occipital artery was filled from the vertebral artery. When opaque medium was injected into the deep cervical artery (which originates from the costo-cervical trunk), it reached the vertebral artery through anastomoses between these vessels (Fig. 2 D).

In a fourth experiment (Fig. 2 E), medium injected into the transverse cervical artery filled the subclavian artery as well as the axillary artery and its branches, namely, the acromio-thoracic artery and superior thoracic artery, through the anastomoses between the transverse cervical and acromio-thoracic arteries. The subclavian artery had previously been ligated in the neck, distal to the origin of the transverse cervical artery. Two clips were put on the vertebral artery. Medium injected into the costo-cervical trunk filled the vertebral artery through anastomoses between these vessels (Fig. 2 F). The medium also reached the subclavian artery and axillary arteries through anastomoses between the acromio-thoracic and deep cervical arteries. The subclavian artery had previously been ligated distal to the costo-cervical trunk, and the vertebral artery ligated at its origin.

Left: The opaque medium injected into the ascending cervical artery (white arrow) filled the vertebral artery (1) through anastomoses between them. Center: The opaque medium injected into the transverse cervical artery (6) reached the vertebral artery (1) through the anastomoses between them. Right: The opaque medium injected into the deep cervical artery (7) reached the vertebral artery (1) through anastomoses between them.
Fig. 2 E. Opaque medium injected into the transverse cervical artery (white arrow) filled the subclavian artery (4), the axillary artery (11) and its branches, namely the acromio-cervical artery (15), and the superior thoracic artery (14). The subclavian artery had previously been ligated distal to the beginning of the transverse cervical artery.

Fig. 2 F. Opaque medium injected into the costo-cervical trunk (white arrow) filled the vertebral artery (1) through anastomoses between them. The medium also reached the subclavian artery (4) and the axillary artery (11). The subclavian artery distal to the costo-cervical trunk, and the vertebral artery at its origin, had previously been ligated.
Fig. 3. A. The brachio-cephalic trunk (8), the subclavian artery (4) proximal and distal to the origin of vertebral artery (1), and the axillary artery (11) were clamped and both vertebral arteries ligated.

Collateral Circulation Between the Internal Thoracic Artery and the Intercostal Arteries. In our next group of experiments, both vertebral arteries were ligated at their origins, and then the brachio-cephalic trunk, the subclavian artery proximal and distal to the origin of vertebral artery, and also the axillary artery were clamped (Fig. 3). Opaque medium injected into the isolated internal thoracic artery (Fig. 3 A) on which two clips had been put filled the vertebral arteries on both sides through many anastomoses between the intercostal arteries and the branches of subclavian artery at its cephalic end. This collateral circulation was distinctly seen in the lateral trigonum region (Fig. 3 B).

The internal thoracic artery was then isolated between clips, and the subclavian artery was clamped distal to the origin of the thyro-cervical trunk (Fig. 3 C). Opaque medium injected into the internal thoracic artery then reached the axillary and brachial arteries through the anastomoses existing between the intercostal arteries and the branches of the axillary artery (Fig. 3 D), namely, the intercostal superior thoracic, acromio-thoracic, and lateral thoracic arteries. The aorta and its branches were filled with opaque medium which passed through posterior intercostal arteries.

Discussion

Our experiments were designed to obtain more information concerning the morphological possibilities for collateral blood supply to the brain and the upper extremity. They can serve only as a general guide and do not possess any statistical value. Some of them correspond well with situations encountered in clinical practice; others have an artificial character and do not correspond to any known clinical model. The results, however, suggest more possibilities than had been anticipated for collateral blood supply.

Fig. 3 B. Opaque medium injected into the isolated internal thoracic artery (white arrow), filled the vertebral arteries (1).
Among arteries that can play a role in this collateral supply, the following should be taken into particular account: the occipital, the transverse cervical, the costo-cervical trunk, the thyro-cervical trunk, the internal thoracic, and the intercostal arteries.

These results facilitate understanding of the variety of clinical forms encountered with occlusive lesions in specific sites of the arterial field between the aortic arc and the arterial circle of the brain. It should be stressed, however, that the fact of morphological possibilities for collateral supply does not necessarily guarantee functional sufficiency.

Summary

Anatomical studies were performed to identify the possible channels of collateral circulation to the brain and upper extremity. These investigations involving anastomoses between elements of the posterior aorto-cerebral circle and other arterial areas point to numerous branches which may serve as channels of the collateral circulation.

The main channel of collateral circulation is the occipital artery, between the vertebral artery and external carotid artery, while that between the posterior aorto-cerebral circle and the subclavian artery seems to be the thyro-cervical and costo-cervical trunks. In cases of occlusion of the brachio-cephalic trunk, the internal mammary artery may constitute a valuable channel of collateral circulation. When occlusion of the subclavian artery extends into the internal mammary and vertebral arteries, the intercostal arteries may be involved.

These anatomical studies provide information classifying the variety of clinical
symptoms that may be encountered in cases of arterial occlusion affecting the blood supply to the brain and upper extremity.

References


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